OAR:
The Basic Research Agency
of The United States Air Force

AF OFFICE OF SCIENTIFIC RESEARCH / A F CAMBRIDGE RESEARCH LABORATORIES / AERONAUTICAL RESEARCH LABORATORIES / EUROPEAN OFFICE O A R

NO. 18 19 NOVEMBER 1962

APPROACH TO MORE POWERFUL MAGNETS

Optical Physics Laboratory (AFCRL)

Rigid barriers to the realization of magnets of increased power are internal forces and temperature. The temperature problem is more amenable to solution than the force problem. To mitigate high temperatures, elaborate liquid cooling techniques are used; furthermore, much progress has been made toward the development of the superconducting magnet which inherently will relieve thermal difficulties.

The force problem has received much less attention. For huge and powerful magnets in the megagauss region, forces of more than 300 tons per square inch are generated. These forces are more than the magnet material can withstand. The crystalline structure of the material breaks down and the magnet loses structural integrity. If these forces were eliminated or alleviated, more powerful magnets could be built, or greater power could be built into magnets of smaller size. More powerful magnets are needed in many research fields and Air Force operations, among these being ion propulsion engines for deep space vehicles.

In a paper published in the September Physical Review, M. A. Levine and G. L. Hand of AFCRL discussed a new approach to the creation of force-free magnetic fields--an essential step in relieving the stresses exerted on magnet materials.

The concept for the force-free magnetic field grew out of a consideration of the vast magnetic fields existing throughout the universe. In spite of these large fields, no forces are exerted, and thus they have little known effect on the gross dynamics of the universe. The magnetic fields in space are created by current flowing in the plasma which comprises the great bulk of the material of the universe. On a smaller scale, similar force-free magnetic fields are created in laboratory plasma experiments. The explanation for the lack of forces in both the huge magnetic fields in space and the small fields in laboratory plasmas is that when magnetic fields are created by some gaseous, non-solid mechanism, the current vector and the magnetic field vector are always parallel.

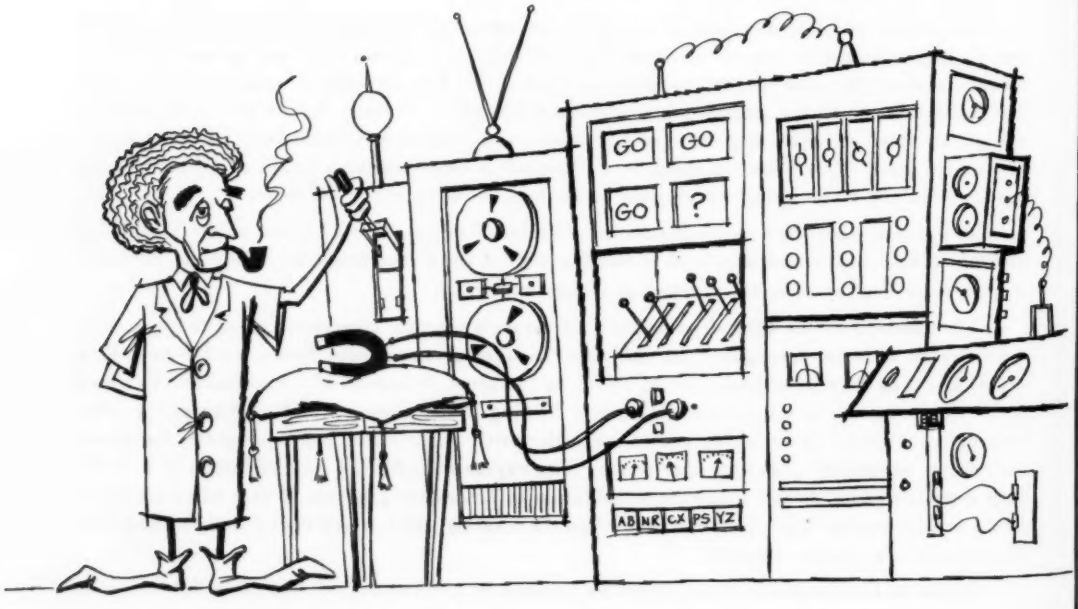
If a force-free magnetic field could be created by a solid magnet, the powerful forces on

the magnet material could be alleviated. The goal of the AFCRL research is not to eliminate the forces exerted on the magnet (because in this case the magnet could do no useful work), but to spread the forces over a larger area. At present, these forces are concentrated at certain points. To spread the forces over a larger area, there must be a zone in the magnetic field that is force-free, and there must be a careful gradation of force values at other parts of the magnetic field. This requirement obviously presented problems of considerable mathematical complexity.

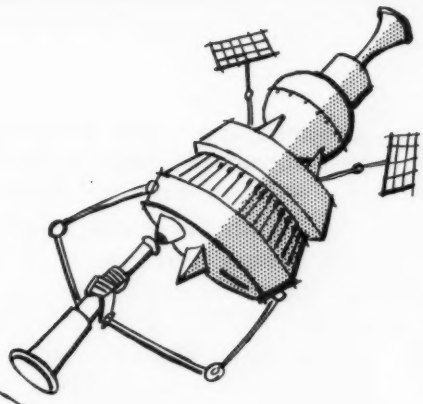
Research to date has largely focused on the mathematics of the problem. The mathematical approach is to determine the precise geometric contouring of the conducting wire layers which will result in the force-free zone in the magnetic field. Magnetic fields with two distinct components were investigated. An example of such a field is that created by a torus (donut shaped) magnet where there is a circular or toroidal field surrounding the torus and a second field passing through the torus. It was found, mathematically, that a force-free zone could be established at the interface of these two components. To achieve this force-free zone, the magnitude of the components must be equal across this interface.

But a force-free zone in the magnetic field cannot be realized using the simple configuration of the torus. The mathematics of the problem dictate that the layer of conducting wire assume a configuration of enormous complexity. The windings of the conducting wire may graduate from a simple helix to an eliptical helix, which in turn evolves into increasingly larger spiral and so on. For multiple layer wiring, both the mathematical and the fabrication complexities increase by orders of magnitude.

Nevertheless, AFCRL has already begun to undertake the study of methods whereby such magnets can be wired. Several configurations have been fabricated in the laboratory. From this research, together with the much greater amount of research at other research laboratories on superconducting magnets may come the essential techniques for overcoming problems of force and temperature which presently set a barrier to the design of more powerful magnets.



satellite-borne infrared interferometer



Optical Physics Laboratory (AFCRL)

A new infrared interferometer recently developed by AFCRL and carried aboard an Air Force satellite gave AFCRL scientists the sharpest view yet obtained of the continuously varying temperature patterns of the earth and chemical constitutents of the atmosphere. The infrared interferometer satellite experiment was carried out under the direction of Louis Block of AFCRL.

The six-pound interferometer achieves its high spectral sensitivity by making full use of its total viewing aperture. The aperture of a conventional infrared spectrometer is limited at any one time to a narrow slit and a rotating prism or grating, an arrangement necessary for obtaining resolution. The AFCRL infrared interferometer operates over a wavelength range of from 1.8 to 16 microns. Future plans include using a similar type of interferometer to make radiation measurements from a satellite in the ultraviolet and visible regions of the spectrum.

From its satellite platform, the new interferometer spectrometer obtained a 50-mile view of the earth during each one-second period of observation. Although a great deal of infrared data has been taken from the ground and from aircraft, little research data has been gathered by infrared spectral devices looking down through the atmosphere.

Infrared radiation is emitted by all objects, gases, or particles whose temperature is above absolute zero. Each chemical constituent has a characteristic infrared signature. The features of this signature, consisting of peaks on an infrared emission spectrum, change with temperature. In addition, a continuum radiation is emitted from every body. With increasing temperature, the amount of this continuum increases, and its peak falls at a higher frequency (shorter wavelength) on the infrared spectrum. By the analysis of the spectrum, it is possible to determine the presence of a given chemical constituent and its

temperature. The temperature of the earth can be determined from the location of the peak in the continuum.

With the small satellite-borne infrared interferometer, scientists will have a more precise tool for measuring the earth's albedo -- that is, the ratio of the amount of solar radiation falling on the earth relative to that reflected. The interferometer will also permit the observation of the thermal and chemical properties of aurorae, the observation of radiation scattered from cloud patterns, and the observation of generalized temperature patterns over the earth.

North American *OZONE* network

Meteorological Research Laboratory (AFCRL)

The most thorough study of atmospheric ozone ever made is planned by scientists at the Air Force Cambridge Research Laboratories. During a concentrated one-year series of observations, more than 700 balloons will be used to carry extremely sensitive ozone meters into the extreme upper atmosphere.

The observational program has been in the planning stage for three years by AFCRL scientists. The program calls for a network of eleven observational stations over the North American continent extending from the Canal Zone to Thule, Greenland. Each week throughout the year, beginning in January 1963, eleven balloons - one from each station - will be released simultaneously.

In addition to these scheduled weekly measurements, the program calls for a 15-day series of daily launches to be made at each station in the spring (of 1963) when ozone concentrations in the atmosphere are most intense. The balloons used in the program inflate to a diameter of 25 feet at their maximum altitude of 100,000 ft.

Although ozone is a minor constituent of the atmosphere, its influence on the earth environment is great. The earth's radiative heat balance and thermal structure of the stratosphere is to a large extent controlled by the distribution of ozone. Together with carbon dioxide and water vapor, ozone is a principal absorber and emitter

of solar radiation at certain frequencies. Ozone effectively shields the earth's surface from the destructive effects of direct ultraviolet radiation from the sun.

In charge of the AFCRL ozone observational program are Wayne Hering and Robert F. Myers who initiated the program and planned and organized the eleven station network. The network was made possible, however, by the recent development of an extremely efficient ozonemeter by V. Regener of the University of New Mexico under contract to AFCRL. The chemiluminescent ozonemeter is simple, rugged and requires a minimum of pre-flight preparation.

Field tests of the Regener ozonemeter have been in progress both at the University of New Mexico and AFCRL since 1961. Performance characteristics have proved highly satisfactory. The North American network was established in collaboration with universities in the United States, the Air Weather Service, and the Department of Transport in Canada.

The instrumented balloons will be launched each Wednesday at 1200 hours Greenwich time. Data from the ozone meters will be telemetered to the ground. The network will be supplemented by special flights by AFCRL's U-2 aircraft equipped with a Regener ozonesonde.

The network stations are: The Canal Zone, operated by the Air Weather Service; Florida State University; Air Force Cambridge Research Laboratories in Bedford, Mass.; Goose Bay, Labrador, operated by the Department of Transport; Thule AFB operated by the Air Weather Service; University of Wisconsin; Colorado State University; University of Washington; Eielson AFB, at Fairbanks, Alaska operated by the Air Weather Service; Fort Churchill, Manitoba, Canada operated by the Department of Transport, and the University of New Mexico.

Ozone is a molecule consisting of three oxygen atoms. It is continuously created in the presence of sunlight in the upper layers of the earth's atomosphere. The photochemical and impact reactions involved in the formation of ozone result in a primary source region of 10 to 15 kilometers in depth centered near 25 kilometers over the equator, sloping upward to 30 kilometers at high latitudes. It is

eventually transported to the ground where it is destroyed by interaction with organic materials.

Ozone is of interest to Air Force scientists for many reasons. In addition to its radiation shielding properties, it is a natural tracer of atmospheric motion. Measurement of ozone variability in time and space offers the meteorologist a unique method for investigating circulation processes. Both short-period turbulent eddies and broad-scale features of general circulation can be traced by means of ozone measurements.

In sufficient concentrations, ozone is toxic. Concentrations in excess of fifteen parts per million are lethal to small laboratory animals. It can cause irritation to the human nose, throat, and air passages, and in greater concentrations can cause a tightness in the chest, headache and drowsiness. It also has deleterious effects on certain materials such as rubber.

From the analysis of the data, AFCRL hopes to learn several things about the nature of ozone: the reasons why ozone concentrations in the lower stratosphere increase during the winter and early spring in the higher latitude regions, the reasons for the vertical flux of ozone from the stratosphere into the troposphere, and something of the storage time and mixing history of ozone as it passes through the troposphere to the earth's surface.

LADDERS, BRIDGES and SPRINGBOARDS IN astrophysics

DWIGHT L. WENNERSTEN, General Physics Division (AFOSR)

The certitude of astronomers and astrophysicists in making predictions about and in describing the structure and natural order associated with most of the observable universe around us is based principally on understanding and checking what one "sees" at a known distance. This follows because all celestial objects which provide their own light have such intense heat and radiation fields that close approach is not feasible and man is restricted to observations at a distance.

The primary ladder of astrophysics that gets an observer, figuratively, off the earth's surface is the determination of distance. The simplest case is shown in Figure 1, where the trigonometric basis by which the distances to the nearer stars are determined is sketched.

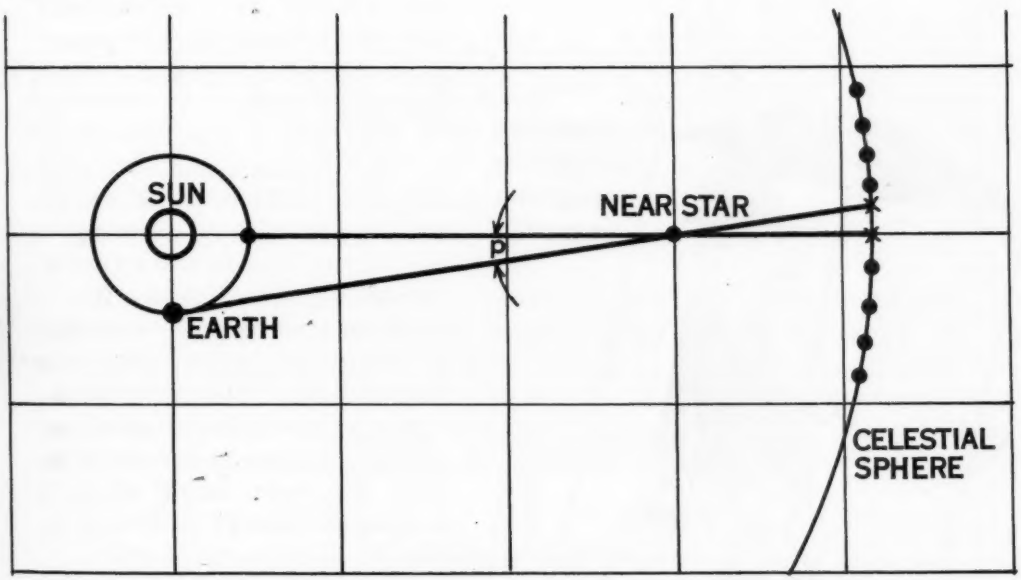


Fig. 1

Here the slight change in apparent direction from two different locations of a telescope to a star, called its parallax, is measurable as a small angle, "p." Figure 1 shows the dimensions con-

cerned in the situation called "heliocentric parallax" since it is based on the radius of the earth's orbit. The apparent motion "x-x" against the star background is a convenient check mechanism. Obviously the largest stellar parallax is that of the nearest star, α (Alpha) Centauri. The observed parallax of 0".751 gives a distance of 4.3 light years or 85 million million miles. Trigonometric parallax can be accurate to 0".01 when extreme care is exercised, so direct measurements of the distances to stars can be made to about 300 light years.

Since the parallax of all stars is less than one second of arc, as mentioned above, all factors contributing to larger variabilities in astronometric measurements had to be identified and corrections to a much lower figure, say 0".01, had to be developed. Among the milestones of precision measurement improvements were:

FIG 2 ABERRATION ANGLE OR POINTING CORRECTION

A. Newton's observation that atmospheric refraction corrections should include not only a factor of the angle from the vertical (zero refraction), but corrections for air pressure (barometric) and temperature, as well.

B. James Bradley's discovery in 1724 of the aberration correction or "pointing" correction due to the earth's orbital velocity. Since the earth has an orbital velocity of 30 km/sec or 10^{-4} the velocity of light, this correction is a maximum for directions at right angles to the earth's orbit and equal to 20" of arc. A simple analogy is shown in Figure 2.

C. Bradley's second important discovery (1748) of the nutation or "nodding" of the earth's axis of 18" total amplitude on a 19-year cycle caused

by the moon's attraction on the earth's equatorial bulge. This factor is superimposed on the 26,000-year precession of the earth's axis due to the sun's differential attraction on the same bulge.

D. Herschel's improvements in the accuracy of constructing parabolic mirrors about 1774. His improved mirrors up to 19 inches in diameter increased telescopic magnification from 450 to 6450.

E. Gauss's development in 1804 of the least-squares approach to errors and most probable values in measurements.

F. Fraunhofer's traveling crosshair, micrometer eyepiece for telescopes, accurate to 0".01.

G. Silver-bromide dry photo graphic plates (1871).

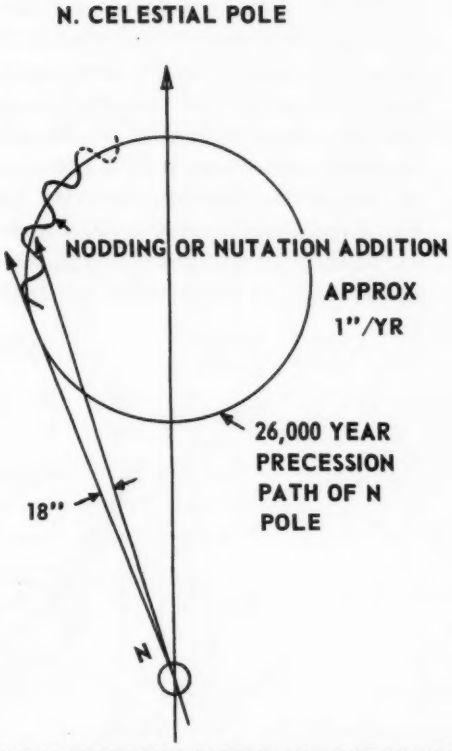


FIG 3 NUTATION (MOON) AND PRECESSION (SUN) PERTURBATIONS ON GEOGRAPHIC NORTH

H. Zeiss's six and eight element, achromatic camera lenses.

Now to return to parallax or distance measurements on stars. In the group of stars thus measurable, there are 37 that are 15 light years or closer. Of these, 14 are double or triple star systems. Up to the distance of 60 light years, 171 stars or multiple stars can be measured accurately, and out to 300 light years the number increases to about 15000.

Given this large a set of data and confidence in its accuracy by direct measurement, a scientist will graph it. The result is Figure 4, the H-R or Hertzsprung-Russell Diagram.

Here the absolute magnitude, or the logarithm of the luminosity of stars at a standard distance of 33 light years, is plotted against

their spectral color or surface temperature. Like parallax measurements, the history of star color classification as blue, yellow or red created some controversies over assignments of surface temperature, but fortunately photographic plate improvements, the spectroscope, and the photoelectric photometer have combined to make temperature determination an exact measurement permitting positive identification among both star classes by temperature and the star types by size such as giant, dwarf, and subdwarf. This is the main bridge to greater distance measurements as the apparent brightness of a star and its color can be used with the inverse square law to calculate its distance.

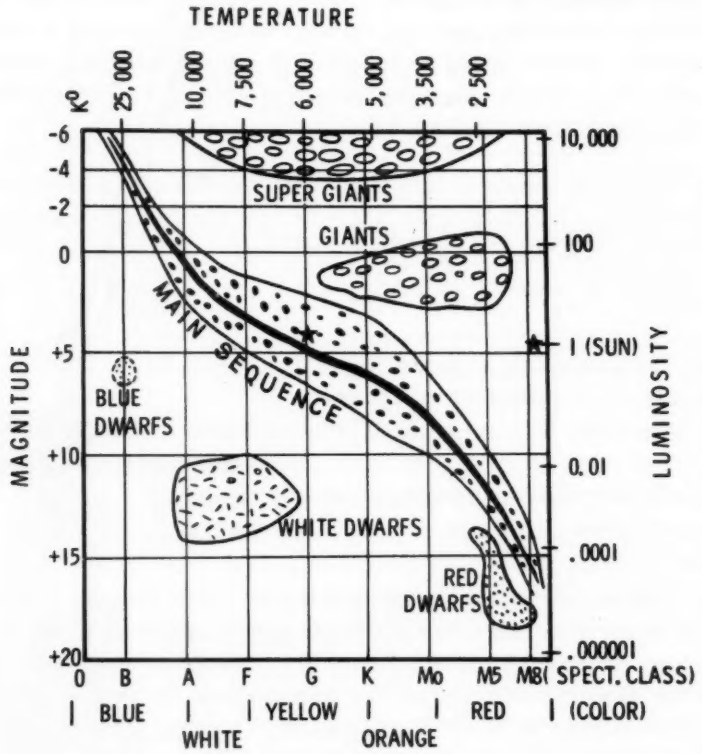


Fig. 4

Figure 4 shows the most concentrated regions of the hundreds of thousands of stars near enough and bright enough to be measured either directly or spectrographically. Ninety per cent lie in the region labeled mainsequence. However, the scatter in data points has led to careful consideration of stellar evolutionary models, to quantitative spectroscopy of various element abundances, and to precise determination of surface temperature. Such studies and comparison

with arc studies in laboratories have established that departure from the heavy curve near the center of the main sequence group is a measure of the "age" of the star since its birth. The original hypothesis to this effect brought on a search for "young" groups or clusters of "measurable" stars. Two such, "h" and "χ" (Chi) Persei, a double cluster of our galaxy, have been found and were analyzed by the Cal Tech group which is supported in part by AFOSR. These clusters are shown in the upper left of Figure 5, where the solid curve is the "main sequence" curve of Figure 4, but in new coordinates. The dashed areas show the magnitude and color of the stars not lying on the main sequence curve.

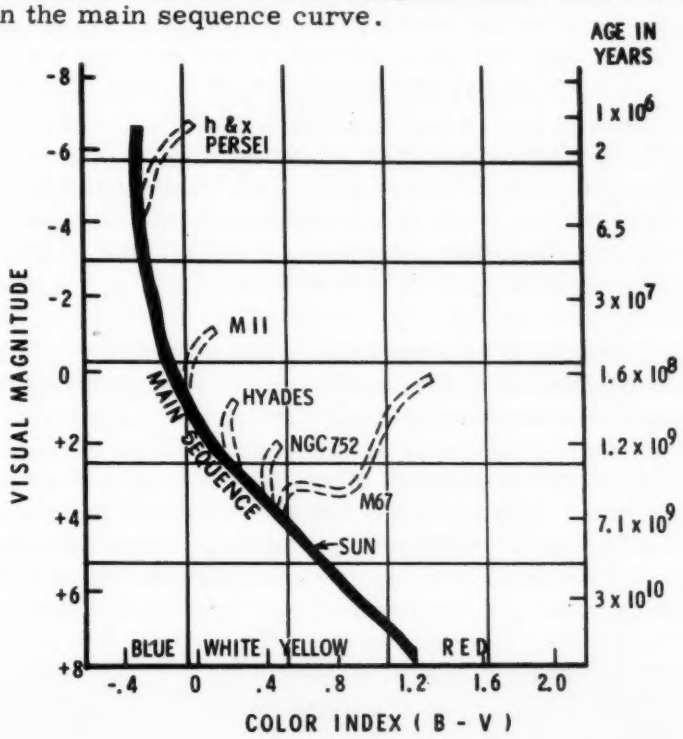


Fig. 5

In this figure, absolute visual magnitude indicated on the left is plotted against a color index proportional to temperature.[1] The scale added on the right indicates the age in years of stars just leaving the main sequence, the junction between the dashed regions

1. The B-V index is a number secured by taking the difference in intensity of a star's light output in the center of the Blue (~4000Å) and the Visual (~5000Å). This has been shown to give an accurate measure of the star's surface (photosphere) temperature as it is proportional to the slope of the black body radiation curve.

and the main sequence "trunk." This junction region is chosen for study because stellar models are most accurate near the main sequence where direct comparison can be made with the sun.

Having found "young" clusters where the bulk of the stars lie on the main sequence and the ones departing from it are but five to six and a half million years old (veritable infants in terms of usual cosmologic ages), the other end of the scale then becomes interesting. Thus the "oldest" group of stars found was the cluster M67, where all the blue and white large stars have burned enough of their hydrogen to depart from the main sequence, cooling off to a red color, and where yellow stars of mass about 1.3 times that of the sun are just leaving the main sequence and starting their heat-pulse cycle. Thus in our neighborhood or galaxy, there are star groups of average ages varying from 6×10^6 to 7×10^9 years or by a ratio of 1000:1. Also shown are other "age" groups, such as clusters M11, the Hyades, NGC752 to name a few, distributed between these limits. We conclude from these measurements that the firmament was not populated by stars in one day. In fact one is led to ask, "Are new stars being created?" The answer is "yes".

There are three mechanisms which contribute. The first relates to the statistical problem of a stable star forming from galactic gas and dust. Protostars or immature partial stars are probably formed when local regions in space form a swirl of hydrogen gas and dust around a common center. Gravity then takes over and the matter forms a nucleus. The gravitational center then attracts or "sweeps up" more as it moves through space until the star nucleus becomes dense enough to meet the temperature-pressure requirements for a main sequence star. If the mass of the new "star" lies in the range 1/10 to 50 times the mass of the sun, the normal life sequence of a red, yellow, white or blue dwarf star results. Gas and dust vortices larger and smaller than this range of sizes break up. This try-and-fail cycle then accounts for most of the large amount of free hydrogen and dust still in the galaxies.

The second source of gas and dust is the normal life cycle of the ordinary main sequence stars themselves. For example, the sun, a small star, emits 4.2 million tons of mass per second in the form of radiation energy and energetic particles. Thus it "gives back" to the interstellar medium. Stars larger than the sun give back more and again, there are even larger stars that become super novae which by explosion return all of their mass to the interstellar medium to be "used" again.

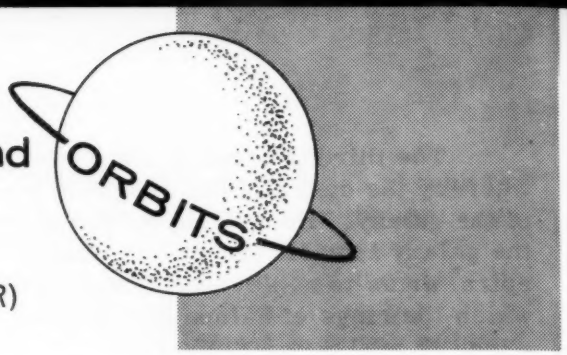
The third process is the "sweeping" process of spiral galaxies whereby the dust and gas from the whole galaxy are fed into the arms of the galaxy. Here, gravity of the central star cluster or nucleus of the galaxy attracts the gas and dust. This material is thrown into the spiral arms to achieve rotational energy balance in a similar way to which the rings of Saturn are formed.

The three processes described show that in our galaxy and in the several thousand near us which we can "see" (observe), stars are born and "reborn" from earlier ashes. Though all evidence so far points to progress down the thermodynamic hill, it is an almost incredibly drawn out process.

In this discussion, the principal observational data rely on the direct measurement of distance; additions by the spectroscope, photographic plate and photometer; and a bit of the simpler nuclear physics of the lighter elements to develop the characteristics of the most populous star class, the main sequence stars. It also leads to the estimate of 15 ± 5 billion years, as the most probable age of the universe. Then too in describing the AF concern about conditions from our position in one arm of the Milky Way galaxy to deep space, it suggests that the safest route calls for travel outside the plane of the galaxy to the maximum extent to avoid the principal concentrations of stars and the more diffuse dust or gas clouds also in the arms.

Thus we are back to the florid metaphor of our title: Using the primary ladder of distance measurement on near stars and the bridge of the spectroscope and photometer to farther fields of stars; the descriptive models of astrophysics can be our springboard into the interesting regions of deep space.

HILL CURVES and ORBITS



MAJOR B. R. AGINS, USAF
Applied Mathematics Division (AFOSR)

The emphasis on space exploration has led to increased research in dynamics. From an advanced, modern point of view, the aim of dynamics is to characterize the totality of possible motions of dynamical systems by their qualitative properties; i.e., existence, stability, boundedness of motion and periodicity.

In 1878, G. W. Hill proposed an investigation into the so-called zero velocity curves associated with the restricted problem of the sun, the moon and the earth. Since that time, these curves have been used to establish certain limitations regarding the regions in which a third body can move.

Working under an AFOSR contract, Dr. Victor Szebehely, of General Electric Missile and Space Division has endeavored to extend Hill's ideas along two lines: to more general dynamical systems in addition to the restricted three body system and to more far reaching applications than the establishment of various regions of possible motions.

Dr. Szebehely's work resulted in the presentation of a set of dynamical systems which possess zero velocity curves, and showed that the restricted three body problem system is not the only member of the set.

Then, conditions on the potential were established for which zero velocity curves will be orbits for members of this set of dynamical systems.

The potential of the restricted problem, in general, does not satisfy the stated condition, except in a few special cases, when the zero potential curve can be used for generating periodic solutions.

The problem of two bodies satisfies the conditions in either fixed or rotating coordinates provided the orbits are circles. Under these circumstances, all zero velocity curves are orbits, but not all orbits are zero velocity curves.

Dr. Szebehely's results assist in the selection of trajectories to accomplish a given space mission within the existing limitations on fuel quantity and thrust.

NOTICE TO OUR READERS

Requests for further information should be directed to the individual or laboratory of origin.

Addresses are as follows:

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
Attn: CRI
Laurence G. Hanscom Field
Bedford, Massachusetts

AERONAUTICAL RESEARCH LABORATORIES
Attn: ARO
Wright-Patterson Air Force Base, Ohio

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Attn: SRIL
Tempo D Building
4th and Independence Avenue, S.W.
Washington 25, D.C.

Detailed documentary reports may be obtained from:

OFFICE OF TECHNICAL SERVICES
U.S. Department of Commerce
Washington 25, D.C.

ARMED SERVICES TECHNICAL INFORMATION AGENCY *
Arlington Hall Station
Arlington 12, Virginia
*Qualified requestors

RESEARCH REVIEW is published by the Office of Information (RREI), Office of Aerospace Research, USAF, Washington 25, D. C. The frequency of this publication is determined solely on the basis of the availability of significant material to report. The objective is to make a positive contribution to the exchange of information about Air Force sponsored and conducted basic research activities. Individuals or groups associated with basic research may obtain copies by written request to the above address.

GPO 935692